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Charles Consel[1,2], Lucile Dupuy[2], Hélène Sauzéon[2,3]

[1] Bordeaux Institute of Technology, 33400 Talence, France
[2] Inria, 33405 Talence, France
[3] University of Bordeaux, 33405 Talence, France

{Charles.Consel, Lucile Dupuy, Helene.Sauzeon}@inria.fr

Abstract. This paper presents HomeAssist: an assisted living platform aims to support aging in place. This platform was designed using a human-centered approach. It offers assistive services, addressing the main aspects of daily life: activities of daily living, home and user safety, and social participation. HomeAssist introduces key novel features: (1) it covers multiple aspects of daily life, addressing a variety of needs of older adults; (2) it provides customization mechanisms, adapting assistance to the user's abilities while preventing autonomy losses; (3) it relies on context awareness, delivering timely assistance; and, (4) it revolves around a unified user interface to achieve usability.
All these features play a key role towards achieving high acceptance of HomeAssist and supporting autonomy effectively, as shown by our field study.

Keywords: Human Factors · Aging in place · Pervasive computing · Field study

1 Introduction

To address the challenge of demographic aging, there is a growing interest for Assistive Technologies (AT) dedicated to aging in place. Today, ATs are regarded as one of the most promising ways to meet needs of older adults at home, particularly in the three domains sensitive to late senescence: everyday activities, including basic and instrumental Activities of Daily Life (ADL) (*e.g.*, reminding drug intake with a connected pillbox), safety at home (*e.g.*, detecting falls with a wrist-worn fall detector), and social participation (*e.g.*, relating to others with collaborative games) [1]. Unfortunately, the growing supply of ATs for aging in place does not translate into technology adoption by older adults [2, 3]. As a result, researchers in the field of Aging and Human Factors have investigated the factors affecting technology acceptance amongst the elderly population. According to the Senior Technology Acceptance Model [4], and previous related studies, three main factors are identified as barriers or assets of technology acceptance: 1) the characteristics of older persons (*e.g.*, perceived needs, technological skills, medical conditions, *etc.*), 2) their environment (*e.g.*, social support for using AT, living place, *etc*.), 3) the features of technology (*e.g*., hardware, interface accessibility, usability, *etc*.) [4, 5].

Despite considerable efforts for leveraging the knowledge on aging and human factors, several issues remain to be resolved [6]. A key issue is concerned with the silo-based approach currently used in the development of both research and industrial ATs; that is, a single AT addresses a single task or need. This silo-based approach has many consequences. First, it gives rise to a challenge regarding the number of ATs that can be introduced, as the older adult requires more services to assist an increasing number of daily activities. Second, the heterogeneity of interfaces across technologies incurs an unrealistic cognitive load on older users for learning these technologies. Third, due to the intra- and inter-individual variability and evolution of needs, assistive technology support must be adaptable (*i.e*., providing a personalized set of services). In doing so, assistive technology support can account for spared abilities, thus avoiding the risks of functional losses elicited by the AT use. The fourth consequence, related to the silo-based approach, is the lack of context awareness of assistive services. This situation results in services that deliver assistance irrespective of the actual person's needs and context, potentially making assistance unsuited or even obstructive in daily life.

The field of technology and aging has been pushed forward with the advent of Ambient-Assisted Living (AAL) where digital devices are spread everywhere to optimize and naturalize interactions between the individuals and their physical surrounding [7]. Basically, AAL consists of sensors (motion detectors, contact sensors, *etc.*) and actuators (connected door locks, smart plugs, notifications on mobile devices, *etc*.); it can be seen as a processing system with perception-action loop driven by software services supporting users to achieve specific goals, or to anticipate possible outcomes of their actions. AAL has the potential to integrate a range of technologies, products and services for promoting aging in place. Queiros *et al.* examined this promising approach by performing a systematic review of the AAL literature, analyzing a total of 1,048 studies [7]. They reported that only 10% of these studies were related to user issues (accessibility and usability, in particular), clearly revealing the technology-oriented approach of this new field of AT for older adults. Also, among the 13% of technologies with a practical purpose, only 0.04% (N=6) has been tested in field trials. As already observed in a previous review [8], these field studies are reported as lacking empirical evidence of AAL efficacy, mostly due to the study designs with often small sample sizes, non-standardized measures (*i.e*., self-made measures), experimental home setting (rather than real homes), and an absence of a control group.

The HomeAssist project aims to contribute to the field of AAL. It is designed to support aging in place with assistive services, addressing the main aspects of daily life: activities of daily living, home and user safety, and social participation. In doing so, HomeAssist introduces key novel features: (1) it covers multiple aspects of daily life, addressing a variety of needs of older adults; (2) it provides customization mechanisms, adapting assistance to the user’s abilities while preventing autonomy losses; (3) it relies on context awareness, delivering timely assistance; and, (4) it revolves around a unified user interface to achieve usability. These features play a key role to achieve high acceptance of HomeAssist and supporting autonomy effectively, as shown by our field study.

Outline. This paper is organized as follows. Section 2 presents the human-centered design of HomeAssist and its key components, namely, an open-ended catalog of assistive services, covering a range of user needs (Section 2.1), an infrastructure of devices and software services, supplying information to the assistive services (Section 2.2), an activity detection system, providing context awareness to assistive services (Section 2.3), and a notification system, accounting for older adults characteristics for user interactions (Section 2.4). Section 3 reports on the evaluation of HomeAssist. In particular, we assessed the sensitivity and reliability of the activity detection system (Section 3.1), the effectiveness and learnability of the notification system (Section 3.2), the user experience of HomeAssist (Section 3.3), and its efficacy (Section 3.4). Section 4 provides concluding remarks.

2 Design of HomeAssist

HomeAssist was designed using a human-centered approach, driven by a needs analysis of target older adults and their caregivers, formal and informal. Additionally, a range of stakeholders in the aging domain were involved in the design process, including caregiving organization, municipalities, senior residences, and the French national retirement organization.

Specifically, the design of HomeAssist included five key phases: needs analysis, requirements analysis, development of assistive applications, ergonomic evaluation, and benefits evaluation.

1) Needs analysis examined activities that are sensitive to age-related decline and essential for independent living. Additionally, capabilities of the target user population were gathered along such dimensions as cognitive functioning, sensorimotor abilities, and attitudes towards technology.

2) Requirements analysis identified goals related to independent living and assistive or compensation strategies to achieve them, inspired by the environmental support hypothesis, promoted by such researchers as Rogers and Morrow [9].

3) Development of assistive applications addressed the needs analyzed earlier, while fulfilling the requirements. Assistive applications were developed in conformance to ergonomic standards specific to older adults.

4) Ergonomic evaluation of HomeAssist was performed to measure acceptability and user experience.

5) Benefits evaluation for the older user and their social environment was conducted using specific criteria: wellbeing of users and caregivers, as well as user autonomy.

In this section, we first present the assistive services of HomeAssist. Second, we examine the infrastructure that is required to be deployed in a user's home. Then, we focus on two important features of HomeAssist: an activity monitoring system for delivering context-aware assistance and its notification system for assisting the user. Both features are evaluated in Section 3.

2.1 Assistive Services

We conducted a needs analysis for aging in place, recruiting 525 older adults living in their home [10]. Additionally, we collected the needs for assistive technologies to support aging in place from 100 older participants and their caregivers [11]. We grouped the resulting needs into three domains of assistance: activities of daily living, user and home safety, and social participation. We selected a subset of needs and defined requirements for each of them. This work led to the development of assistive applications. Let us present these applications according to the three domains of assistance.

Activities of daily living are covered by applications that monitor tasks (meal preparation, self-care, dressing, *etc*.), report activity assessment to the user and/or caregiver, and remind appointments and other events.

User and home safety are provided by applications that light a path to the bathroom at night, monitor the stove, and alert a caregiver in case of an unusual situation (*e.g.,* no activity during the day).

Social participation is addressed by a range of applications, including a simplified service of email, a service for video-conferencing, and services for leisure activities according to the user's interests (gaming, news, reading, *etc*.).

The HomeAssist applications reside in an extensible, online catalog, in the spirit of the ones for smartphones. In doing so, our platform offers a modular response to the needs of individual older adults and their caregivers in that they can select the specific applications that address the challenges of the user. Additionally, each application is configurable, allowing assistance to be further personalized. As a result, each participant has a unique setting of their assisted living platform.

2.2 Infrastructure

Assistive applications rely on an infrastructure of devices and Web services deployed at the home of each user. Devices consist of sensors, monitoring user interactions with the environment, and actuators, allowing to perform actions. Sensors include contact sensors, motion detectors and smart plugs, which measure electricity consumption and can turn off/on a connected appliance. These devices are connected wirelessly to a gateway, which communicates with our server via the Internet. These devices are widely available, easy to configure, and low cost.

Additionally, each home is equipped with two tablets. One tablet is stationary and is placed in a central location in the home. It is the main point of interaction between the assistive applications and the user; this so-called *main* tablet receives a notification when the user needs to be alerted by an assistive application regarding a particular situation. Otherwise, the main tablet turns into a digital frame, displaying photos (family, topics of interest), thus avoiding stigmatization. The second tablet is devoted to social participation and leisure.

Besides devices, assistive applications leverage Web services such as a shared calendar, an email service, a weather service, *etc*.

2.3 Activity Detection

Aging in place critically relies on the functional status of an individual, as reflected by the way activities of daily living are performed. As a consequence, monitoring activities of daily living is essential to determine the autonomy of an older adult and the type and level of support that are needed to ensure their autonomy.

To address this issue, we have developed and tested empirically a new approach, leveraging both the literature on the daily functioning of older adults, and sensor technology [12]. Specifically, our approach uses results from geriatrics research showing that as older adults age their activities are increasingly organized according to a routine to optimize their daily functioning [13]. Consequently, the activities of an older adult can be verified with respect to their declared routines.

Accurately detecting activities is an overarching feature of a platform for aging in place because it allows to deliver context-sensitive assistance to users. In particular, accurate activity detection prevents from notification fatigue, issued by assistive applications monitoring user activities. Assistive applications remind the user of performing a task, only when it is missed.

2.4 Notification System

We have designed and developed a notification system that exploits the preference of older adults for simple interactions and optimize their cognitive resources by using a multimodal coding of notifications (tones, shapes, colors, and text). All assistive applications are required to interact with the user via either a critical or a non-critical notification, depending on the consequence of the situation. Each type of notification employs multimodal coding, as illustrated by Fig. 1 and Fig. 2, respectively displaying a critical and a non-critical notification.

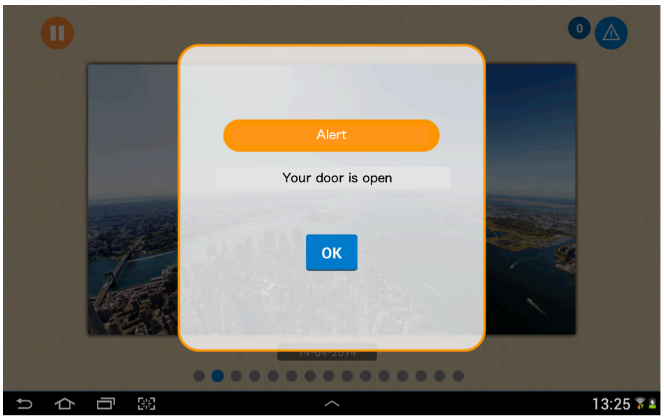


Fig. 1: Critical notification

This approach makes it easier to discriminate between the notification types. Furthermore, the user follows a dedicated procedure for each type of notification.

Critical notifications (Fig. 1) use a loud volume and only disappear when the situation is resolved; it can contact a caregiver via a text message after a pre-defined period of time to seek for help. In contrast, non-critical notifications (Fig. 2) use a soft tone; they disappear after being displayed for a set period of time and get added to a list of unattended (non-critical) notifications. An example of such list is displayed in Fig. 3. This mechanism allows a user to disregard a notification if it occurred while they were performing another task. If the condition that raised a non-critical notification does not hold (*e.g.*, the door of the fridge was closed), then this notification is suppressed from the list of unattended notifications.

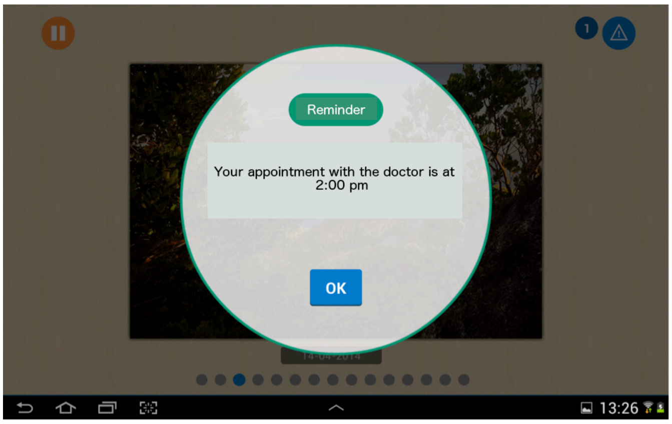


Fig. 2: Non-critical notification

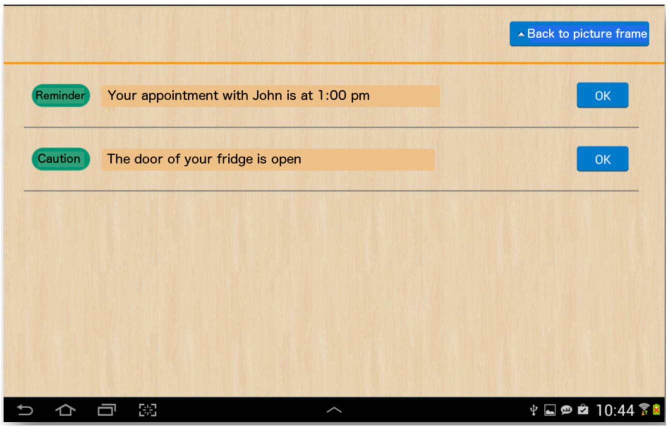


Fig. 3: List of unattended notifications

3 Evaluation of HomeAssist

We now present the evaluation of the HomeAssist platform along four dimensions: accuracy of the verification of activities, usability of our notification system, user experience of our platform, and its efficacy.

3.1 Activity Verification

Recall that our approach to verifying activities is driven by user knowledge, which guides the placement of sensors, tracking the execution of the declared routines. A routine formula gathers key parameters that determine whether an activity is performed. Parameters are derived from the user declarations; they may include an interval of time within which the user is scheduled to perform an activity and selected interactions with the environment are supposed to occur. For example, a user has breakfast between 7:00am and 8:00am, using a coffee machine and milk from the fridge among other interactions. Such parameters are used to calculate a score between 0 and 1. If the activity is not performed, the score is 0, 1 otherwise.

We assessed our knowledge-based methodology to verify daily activities (meal preparation, bathing, and dressing) in the context of a field study, including four single participants, aged 83 years on average (SD=7.89) [12]. It was shown that our approach was as sensitive and reliable as an ergonomist, according to Signal Detection Theory analysis for non-parametric data (Fig. 4).

	Sensitivity (*A'*)	Response Bias (B''_D)
Meal preparation	1.00	0.00
Bathing	0.94	1.00
Dressing	0.93	0.39

Scores obtained by HomeAssist with the ergonomist responses as ground truth (hit, correct rejection, false alarm and miss). A' measures the sensitivity to correctly discriminate the presence or the absence of a stimulus. This measure is contained between 0 (extremely low sensitivity) and 1 (extremely high sensitivity). B''_D measures the response bias: from -1 (tendency to respond yes and produce false alarms) to 1 (tendency to respond no and miss stimuli).

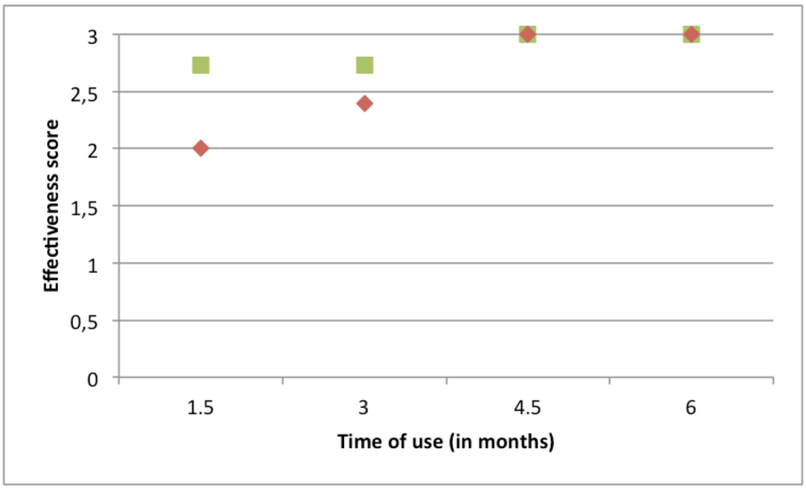
Fig. 4: *A'* and B''_D scores for the three ADL (meal preparation, bathing and dressing)

As illustrated by Fig. 4, both meal preparation and getting dressed were accurately detected by HomeAssist, whereas bathing was well discriminated but sometimes missed. The accuracy of our system provides a solid basis on which to develop a range of assistive applications such as one that reminds daily activities to users.

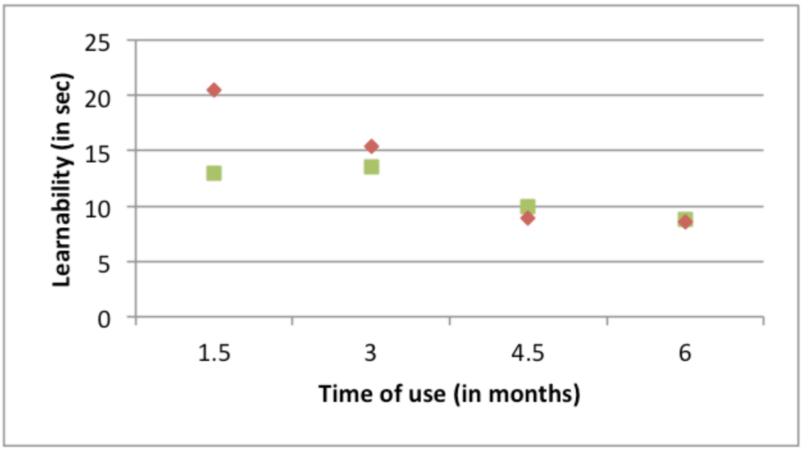
3.2 Notification System

We have evaluated the effectiveness and learnability of our notification system by submitting usage scenarios in our three domains of assistance to 15 older adults, aged 81 years (SD=6.19) [14]. These participants lived alone and were installed HomeAssist in their home. They were evaluated every 1.5 months over a period of 6 months. Results, displayed in Fig. 5, show that participants achieved effectiveness from the start of the experiment and reached an expert level after 4.5 months, regardless of the type of notification (critical or non critical).

Regarding learnability, as shown in Fig. 6, we observe that at six weeks of technology use, participants take more time to respond to a critical notification, compared to a non-critical one. Nevertheless, at six months of use, participants perform equally well, regardless of the type of notification.



Effectiveness scores range from 0 to 3.
Diamond for critical notifications / Square for non-critical ones.
Fig. 5: Evolution of effectiveness

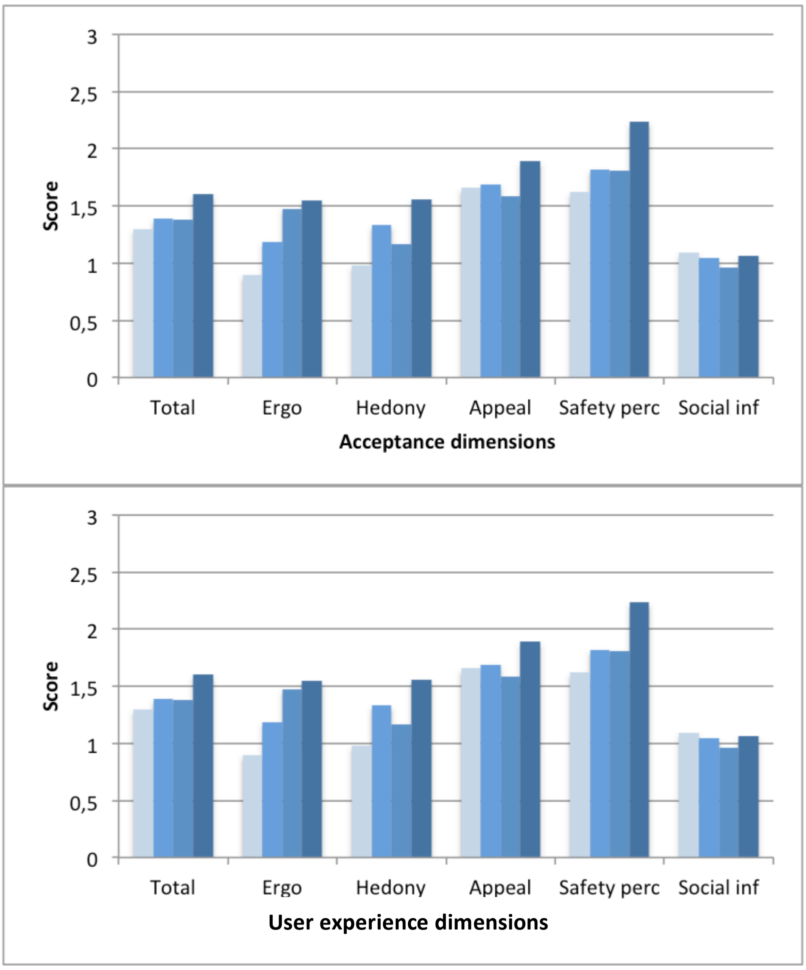


Time is measured in seconds.
Diamond for critical notifications / Square for non-critical ones.
Fig. 6: Evolution of learnability

3.3 User Experience of HomeAssist

We measured user experience of HomeAssist four times over a period of 6 months during which our platform were deployed at the home of 15 cognitively healthy older adults having moderate autonomy losses [14]. Five dimensions of user experience were used: ergonomic quality, hedonist quality, appealingness, safety perception, and social influence. It leveraged Hassenzahl's tool "`attrakdiff.de`" [15].

Results are displayed in Fig. 7 and show that HomeAssist is globally well experienced by users. In particular, ergonomic quality and safety perception are two dimensions that increase over time for most participants. Specifically, 93.30% of HomeAssist users considered the ergonomic quality of our platform between satisfactory and very satisfactory. Furthermore, they found the assistive services provided to them as useful, pleasant, appealing, non-stigmatizing (sometimes rewarding) and reinforcing safety.

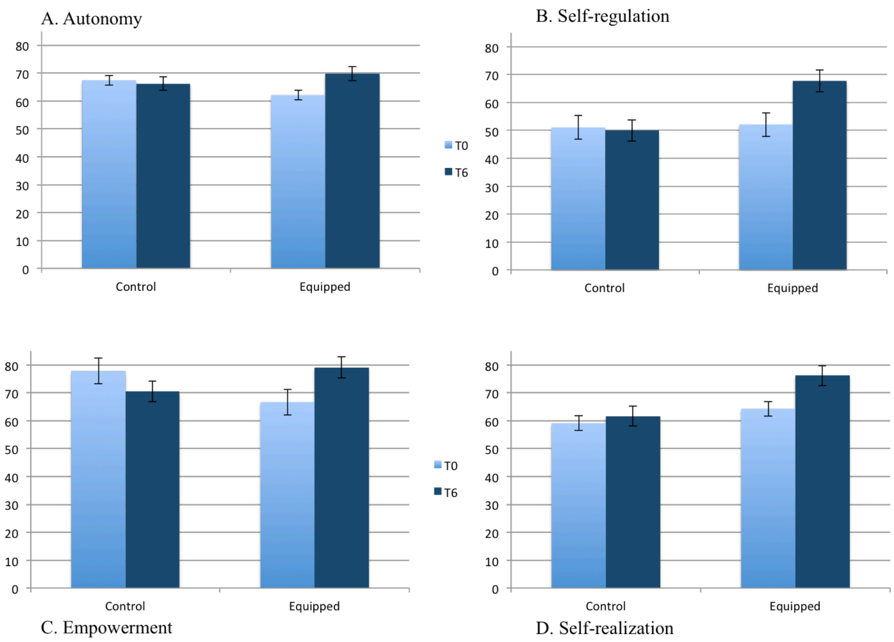


User experience scores from -3 to 3.
Four measures (at 1.5, 3, 4.5 and 6 months) represented by 4 shades of blue.

Fig. 7: Evolution of user experience

3.4 Efficacy of HomeAssist

We analyzed the efficacy of HomeAssist as a tool to support aging in place [16]. This analysis was conducted by comparing equipped participants with their control counterparts using a self-determination scale [17]. All the participants were cognitively spared (MMSE>23 [18]) but physically frail with functional losses from mild to moderate [19, 20]. As shown in Fig. 8, participants equipped with HomeAssist perceived a significant increase in their daily autonomy, self-regulation, and empowerment. These improvements are important because self-determination has been shown to be directly linked to well-being of older adults: the more an individual perceives themselves as being self determined, the better their health and well being (*e.g.*, [21]).



A. Autonomy; B. Self-regulation; C. Empowerment; D. Self-realization
T_0: pale blue, T_6: dark blue

Fig. 8: Evolution of self-determination dimensions (from Dupuy *et al.* [16])

4 Conclusion

We have presented our preliminary results showing that HomeAssist is positively experienced by users, who demonstrated efficacy in using it. This gives insights on the ergonomic value of HomeAssist, such as its high usability and high acceptance. Furthermore, our field study revealed that users of our platform were more self-determined, resulting in improved autonomy and well being. Indeed, the perceptions of behavioral autonomy, self-regulation, self-realization and psychological self-empowerment were increased in the equipped participants.

Another aspect of the efficacy of HomeAssist concerns the caregiver-carereceiver dyad. More precisely, we assessed the caregiver burden for supporting the older adult in their everyday functioning. Results revealed that the caregiver burden has significantly increased for control participants over time, but remained unchanged in the equipped participants [22].

These results are promising and encouraging, suggesting that long-term adoption of HomeAssist is within reach and that it may contribute to prevent functional decline of older adults with mild to moderate loss of autonomy. In turn, these benefits should prevent the caregiver burden to increase.

However, to be generalized, these results need to be strengthened. To do so, we recently launched a large-scale study of HomeAssist, gathering more than one hundred older adults. This research initiative gathers key stakeholders of the domain of aging, including municipalities, French national retirement organizations, companies, and a European agency. It should contribute to formulate health claims (prevention and compensation) regarding HomeAssist that could be guaranteed to users and prescribers.

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